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UNITED STATES PATENT APPLICATION FOR:

PRISM ASSEMBLY WITH CHOLESTERIC REFLECTORS

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BACKGROUND OF THE INVENTIONField of Invention

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The present invention relates generally to optical systems, and more specifically to optical systems used in video and other projection systems.

Discussion of Background

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The functionality of a video projector (illustrated containing a commercially available prism assembly) is explained with reference to Fig. 1A. As shown, white light is generated by the light source. The light is collected, homogenized and formed into the proper shape by the condenser. UV and IR components are eliminated by filters. The white light then enters the prism assembly where it is polarized and broken into

red, green and blue beams. (Hence a "three channel" type prism assembly.) These beams then follow different paths within the prism assembly such that each beam is directed to a specific reflective microdisplay. The microdisplay that interacts with
5 the green beam contains the green content of the full color video image. It is similar for the blue and red microdisplays. On a pixel by pixel basis, the microdisplays modulate and then reflect the colored light beams. The prism assembly then recombines the modulated beams into a white light beam that
10 contains a full color video image. The resultant white light beam then exits the prism assembly and enters the projection lens. Finally, the image-containing beam is projected onto (in this case) the rear of a screen.

Some desirable properties of a prism assembly are that it
15 produce an image in which the brightness and color are spatially uniform and meet other required optical properties including those for brightness, color gamut and contrast ratio. It is equally important that the prism assembly be manufacturable. That is, that the prism assembly be producible in high volume
20 with good yield and at a high quality level. Finally, and of equal importance, is that the prism assembly meet cost targets. Targets that, for consumer products, are inevitably very challenging.

The configurations of several prism assemblies have been discussed in the technical literature. Included are the following:

- 5 •Digital Reflection's Star Prism
- Philip's Trichroic Prism
- IBM's X-Prism + 3 PBS
- S-Vision/Aurora System's Off-Axis Prism
- Digital Reflection's MG Prism
- 10 •ColorLink's ColorQuad Prism
- Unaxis' ColorCorner Prism
- ITRI's Prism
- Primax's X-Prism

15 However, none of these prism assemblies fully meet all of the criteria discussed above. For this reason, LightMaster Systems has invented and developed a prism assembly according to the present invention that more fully meets these criteria. Details of the prism assembly according to the present invention
20 are provided herein below.

SUMMARY OF THE INVENTION

The present inventors have discovered a number of advantages in prism systems that utilize cholesteric layers in one of more optical components of the prism systems. The invention relates particularly to video projection systems utilizing reflective microdisplays. More particularly, in one embodiment, the invention is a configuration of a prism assembly that is based on cholesteric optical components and is suitable for use within a "three channel" LCoS video projector.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1A is drawing of a reflective microdisplay based video projector;

Fig. 1B is an illustration of interactions of unpolarized white light with a "right hand green" cholesteric film;

Fig. 1C is an illustration of interactions of unpolarized white light with a "right hand red" cholesteric film;

Fig. 1D is an illustration of interactions of unpolarized white light with a "right hand green" cholesteric film;

Fig. 2 is an example cholesteric based kernel according to an embodiment of the present invention;

Fig. 3 is an illustration of lightpaths through the cholesteric based kernel shown in Fig. 2;

Fig. 4 is a second example embodiment of a cholesteric based kernel according to an embodiment of the present invention; and

Fig. 5 is an illustration of lightpaths through the cholesteric based kernel shown in Fig. 4.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Each of the prism assemblies discussed herein include cholesteric layers. Technical details about the structure, construction, and operation of cholesteric layers is now discussed. The cholesteric layers are generally thin layers of cholesteric liquid crystal.

The cholesteric layers react with light in a unique way that the present invention takes advantage of to produce efficient prism assemblies. The molecular structure of a cholesteric is such that it interacts with light by either passing or reflecting light of a given wavelength band and polarization. Cholesterics can be produced to either pass or reflect light at the given wavelength and polarization for various polarizations and wavelengths of light (e.g., a "red" cholesteric that reflects light in the red light bandwidth, or a

"green" cholesteric that reflects light in the green light bandwidth, for example).

Referring again to the drawings, wherein like reference numerals designate identical or corresponding parts, and more particularly to Fig. 1B thereof, there is illustrated the interaction of unpolarized white light with various thin layers of cholesteric liquid crystal. The variation of cholesteric layer illustrated in figure 1A can be called "right hand green". In this case, the molecular structure of the cholesteric is such that the layer transmits green left hand circularly polarized light. Green right hand circularly polarized light is specularly reflected. Blue and red light of both polarizations are transmitted. The width of the reflective band (bandwidth) of the cholesteric material is determined as follows:

$$\Delta\lambda = (\Delta n \lambda_{\max}) / n_{\text{avg}}$$

where Δn is the birefringence and n_{avg} the average index of refraction of the cholesteric.

λ_{\max} is the wavelength of maximum reflectivity (essentially, the center of the reflective band.). The efficiency of the reflection can be very high when the light is normally incident to the plane of the film. The efficiency

decreases when the angle of incidence is off normal. In addition, the reflective maximum shifts to shorter wavelengths as the angle of observation increases.

Fig. 1C illustrates the interaction of unpolarized white light with a layer of right hand, blue cholesteric. As shown, all red and green light is transmitted. Right hand blue light is specularly reflected and left hand blue light is transmitted.

Figure 1D illustrates the interaction of unpolarized white light with a layer of right hand, red cholesteric. As shown, all blue and green light is transmitted. Right hand red light is specularly reflected and left hand red light is transmitted.

Cholesteric layers can also be fabricated that are left-handed. In this case, left hand circularly polarized light within the appropriate bandwidth is reflected and right hand circularly polarized light is transmitted.

The cholesteric layer can be in any one of several physical forms. In the first form, the cholesteric is a fluid and must be contained between two substrates (the substrates can be cover glasses or the components in the prism assembly). The layer can also be made in the form of a polymer. It is even possible to utilize an encapsulated cholesteric in the layer.

Some current methods for producing the cholesteric layer include, for example:

A liquid precursor material is introduced into a cell (such as by vacuum filling) and then polymerized in place by exposure to UV light;

5 A liquid precursor material is doctor bladed onto a substrate and subsequently polymerized by exposure to UV light; and

A liquid precursor material is spin coated onto a substrate and then polymerized by exposure to UV light.

10 Fig. 2 is an illustration of a new prism assembly 200 configuration in which each component is named (the prism assembly plus the microdisplays is a kernel). The prism assembly 200 includes 3 polarizing beamsplitters (PBSs) 210, 230, and 270, and a cholesteric based beam splitter (cholesteric prism) 250. Each of the beamsplitters and cholesteric prism
15 perform a part of separating and/or combining, of the individual light paths in the prism assembly. Light entering the prism assembly is basically separated into green, blue and red light paths which are individually directed to corresponding green, red, and blue microdisplays, reflected off the microdisplays,
20 and then combined to produce an output.

In one embodiment, the components of the prism assembly are set in pathlength matched positions. Pathlength matched may be described, for example, as light pathlengths between faces of

the beam splitting components having microdisplays mounted thereon and a reference plane (e.g., exit face 260, or a focal plane in a light management system in which the prism assembly is installed) are approximately equivalent. Thus, individual light beams of each of the separate light beams corresponding to a same image pixel once reflected off the microdisplays arrive at the reference plane after traveling the same distance. And, since the pathlengths within the prism are matched (a pathlength matched prism assembly), distances traveled within the prism by the light beams reflected from the microdisplays are also the same. The prism components themselves are not precise enough, particularly in mass quantity production, to affirmatively bond the prism components directly together and end up with matched pathlengths in the prism. However, *Berman et al.*, U.S. Patent Application No. 10/202,595, filed 7/24/02, entitled "Method and Apparatus for Configuration and Assembly of a Video Projection Light Management System", the contents of which are incorporated herein by reference in their entirety, describes construction of a pathlength matched prism assembly in which standard mass produced optical components may be arranged in pathlength matched positions (e.g., fixed to a plate or frame, and then spaces between the components are filled with an optical coupling fluid such as mineral oil or other commercially available index matching fluid). All of the devices and

construction techniques described in the above referenced patent application may be applied to construction of prism assemblies with cholesteric based beam splitting devices.

In addition, individual beam splitting components of the prism assembly may themselves be constructed as pathlength matched beamsplitters. Construction techniques for beamsplitting devices are described in *Detro*, U.S. Patent Application No. 10/251,225, filed 9/20/02, entitled "Pathlength Matched Beam Splitter and Method and Apparatus for Assembly", the contents of which are incorporated herein by reference in their entirety. The techniques taught and devices described in the above referenced patent application are also applicable to the construction of a cholesteric based pathlength matched beam splitting device, such as cholesteric based beam splitter 250 if constructed as a pathlength matched beamsplitter (the polarizing element of the PBS being replaced with one or more cholesteric layers).

Fig. 3 illustrates the path and polarization of the light at each point within the first prism assembly configuration. PBS 210 divides the input polarized white light into GS, green s-polarized, light and MS, magenta s-polarized light after passing through the magenta dichroic. Quarter waveplate 238 converts the MS light beam to circularly polarized light RHCP-M, right hand circularly polarized - magenta.

A blue component (B-RHCP) of the RHCP-M is reflected off the right hand blue cholesteric 252 of the cholesteric based beam splitter 250 toward the blue microdisplay 262. It passes through a $\frac{1}{4}$ lambda waveplate 256 and is converted to linear polarizatrion. Reflection off the microdisplay imposes pixel by pixel polarization modulation in the reflected beam. Upon reflection by the blue microdisplay 262, the quarter waveplate 256 reconverts the image containing blue component back to circular polarization (now left hand), B-LHCP, which then passes through both the right hand blue cholesteric 252 and the red cholesteric 254 toward the output (an additional quarter waveplate 268 is inserted to convert the light beams back to linear polarization for output).

A red component, R-RHCP, of the RHCP-M passes both of the cholesterics 252 and 254 and interacts similarly with quarter waveplate 258 and the red microdisplay 264. Upon reflection by the red microdisplay, the red component (or red light beam), now left hand circularly polarized, reflects off the left hand red cholesteric directing it toward the output. Both the red and blue light beams are recombined with the green light beam in PBS 270.

In general, there are many different combinations of polarizations and orientations of the various components discussed herein may be utilized. What is needed is a

consistent set of orientations, and the main point is to use cholesterics in combination with a selected polarization to direct a specific light beam to an appropriate device that processes the light (e.g., a microdisplay).

5 Fig. 4 is an illustration of another example prism assembly configuration. Figure #5 illustrates the path and polarization of light at each point within the second prism assembly configuration.

10 Note that the illustrations indicate only the key optics in the configurations. The actual prism assembly may require additional components. More specifically, a "clean-up" polarizer can be inserted to S polarization path of the PBS to improve the contrast ratio. Preferably, this would be a reflective polarizer. In addition, "spacer glasses" can be
15 inserted between any of the "cubes" to equalize the optical path lengths from the reflective surfaces of the microdisplays to the output face of the prism assembly.

20 Also note that the "joints" between the components in the optical path can be conventional, that is, a rigid adhesive. Alternately, the joints can be liquid filled as described in U.S. provisional patent application entitled "An Improved Configuration and Means of Assembling the Light Management System used in a Microdisplay Based Video Projector" submitted September 2001, and Berman et al., U.S. Patent Application,

Serial No. 10/202,595, filed 07/24/02, entitled "Method and Apparatus for Configuration and Assembly of a Video Projection Light Management System". A further advantage of utilizing liquid filled joints is the possibility of reducing component count by eliminating the spacer glasses by adjusting the thickness of the liquid joints. Alternately, the gaps can be "filled" with air (possibly requiring anti-reflection coatings on exposed surfaces).

An additional configuration alternative available to both prism assemblies is to replace one or more of the PBS with a reflective polarizer oriented at 45 degrees (at this time, such reflective polarizers are produced by Moxtek, Inc.). Furthermore, the magenta dichroic in the second configuration can be a flat component oriented at 45° in air rather than the illustrated cube structure. In both configurations it is possible to reduce part count by placing the dichroic films on adjacent prism component rather than placing them on separate components.

In both example configurations, the light output from the prism is linearly polarized but the green polarization direction is orthogonal to that of the red and the blue. In some video projector applications, such as those in which the screen contains a linear polarizer, it is desirable that all the light output by the prism be linearly polarized in one direction. This

can be accomplished by placing a wavelength specific retarder in optical series with the output beam. (Such material is produced by ColorLink Corp and called a ColorSelect. It is a half waveplate in the green portion of the spectrum and a 0 or 1
5 lambda retarder in the red and blue portion of the spectrum.)

Note that configurations can be adjusted so that the prism assemblies can accept not only unpolarized input light but also light that is either linearly or circularly polarized. This is accomplished by the placing an appropriate waveplate at the
10 input to the kernel.

A comment related to the cholesteric layer. Since the nominal light ray is incident on the cholesteric layer at 45 degrees, the center wavelength of the cholesteric (λ_{max}) should be chosen such that the shift towards the blue places the
15 reflective/polarizing band of the cholesteric at the desired portion of the spectrum.

In describing the present invention illustrated in the drawings, specific terminology is employed for the sake of clarity. However, the present invention is not intended to be
20 limited to the specific terminology so selected, and it is to be understood that each specific element includes all technical equivalents which operate in a similar manner. For example, when describing cholesteric composed of a layer of cholesteric film, any other equivalent device, such as a cholesteric liquid

embedded between layers of glass, or another device having an equivalent function or capability, whether or not listed herein, may be substituted therewith. Furthermore, the inventors recognize that newly developed technologies not now known may also be substituted for the described parts and still not depart from the scope of the present invention. All other described items, including, but not limited to prisms, optical elements, depositions, films, encapsulated materials, fittings, air gaps, spacer elements, angles of incidence, re-arrangement or alternative placement of materials, etc should also be considered in light of any and all available equivalents.

In light of the above teachings, numerous modifications and variations of the present invention are possible and will be apparent to the ordinarily skilled artisan. And, appended hereinbelow are a number of embodiments in which the invention may be practiced. However, it should be understood that within the scope of the appended embodiments, the invention may be practiced otherwise than as specifically described. Furthermore, the scope of any non-provisional patents that issue from this provisional application should only be limited by claims as then presented in each corresponding non-provisional patent application, and not be interpreted, affected, or limited from any embodiments or example claims that may be presented herein.